Manuscript MS. 510 M.
2/27/20

MORTALITY OF BROODS OF THE WESTERN PINE BEETLE IN INFESTED BARK EXPOSED TO DIRECT SUNLIGHT.

By J. M. Miller,

Assistant Forest Entomologist, Forest Insect Investagations,

Bureau of Entomology.

ASHLAND, OREGON.

February 27, 1920.

These pages sent Miller by ADH with his letter
of Mar 19 -
Returned to Craighead by Miller with his memo
of Apr 23/20.

510, M

Solar Heat Method for Control work against the Western Pine Beetle (Dendroctonus brevicomis)

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MORTALITY OF BROODS OF THE WESTERN PINE BEETLE IN INFESTED BARK EXPOSED TO DIRECT SUNLIGHT.

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INTRODUCTION

Burning of the infested bark has been the only method in common use for destroying broods of the Western pine beetle (Dendroctonus brevicomis, Lec.) in control operations. The reason for this method, as stated in publications of the Bureau of Entomology,* is due to the fact that the larvae, at a very early period in their development, enter the outer bark of the tree where they complete the feeding period and transform to pupae and new adults. As a rule infested trees can first be distinguished by the fading and subsequent coloring of the foliage, a condition which is seldom noticeable until the broods have advanced far enough in development to reach the outer bark. Mere peeling of the infested bark after this condition

Footnote: * Hopkins, Dr. A.D. - 1909-Barkbeetles of the Genus Dendroctonus, U.S.D.A. Bull. No. 83, part 1.

has been reached will not kill the broods and burning has therefore been adopted as the only method which will insure satisfactory results in direct control projects.

As a result of this necessity for the use of fire, control operations have been limited to the winter and spring seasons because the fire hazard to surrounding timber during the summer season is a real one in many yellow pine stands. It has been found that the precautions, which must be taken during the fire season to insure against spread of the bark fires to the adjacent timber, add a prohibitive expense to the cost of control work.

At the same time it has been recognized that were it not for this fire risk many advantages can be claimed for carrying on control operations during the summer season. Of first consideration would be the opportunity to treat infested summer brood trees and to use trap trees as recommended by Dr. A.D.Hopkins* in

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Hopkins, Dr. A.D. - Some Insects Injurious to Forests. U.S. Dept. Agr. Bur. Ent. Bull., No. 58, p. 28. 1910.

as a means of localizing and controlling attacks of the beetles.

During the season of 1919 a series of experiments were carried out on the Sequoia National Park to determine the effectiveness of felled trap trees in attracting the attacks of the western pine beetle during the summer ~~season~~ period. The data secured incidentally from this study indicated that burning of the infested bark is not always necessary to kill the broods, but that exposure of the bark to direct sunlight during the heat of the day will accomplish the same result. The field work of these experiments was carried out by Entomological Ranger Albert Wagner, to whom the discovery of this point is largely due.

I - FIELD DATA INDICATING MORTALITY OF BROODS IN INFESTED BARK EXPOSED TO SUNLIGHT

1. Condition of Broods Noted in Infested Bark left on the Ground in Positions exposed to Sun.

In carrying out the trap tree experiments in 1919 it was planned to employ such precautions as would make it possible to burn the infested bark on all trap trees so as to prevent the

broods from emerging and attacking surrounding green trees. During the early part of the season, in May and June, the infested bark was burned as soon as it was peeled, but later this operation was delayed because of periods of hot dry weather. It was then found that the broods were being killed in sections of the peeled bark which had been left lying on the ground where they were exposed to the sun during the heat of the day. This point was first noted in a trap tree attacked early in June and peeled on July 17 as will be shown in the following records:

Trap tree No. C11. D.B.H. 40 inchs, Ht. 125 feet.

May 23, 1919. Tree felled.

June 6, " First attacks on main trunk by western pine beetle.

Jul 17, " Brood had advanced to maximum full grown larvae and pupae. Bark loose and peeling was completed. An effort was made to burn the bark, but because of difficulty of controlling fire the burning was discontinued awaiting more favorable weather conditions. Bark was left lying on the ground, some pieces several feet from the log, where

they had fallen in peeling, in positions exposed to the sun.

July 20, 1919 Burning of bark still impracticable. It was found however that, in all sections of bark which had been lying in positions exposed to the sun during the hottest part of the day, broods were not active but to all appearances dead. Where the bark was left lying under the log or in shaded positions broods were developing normally.

July 25, 1919 In examination on this date found only dead larvae and pupae in bark exposed to sun. Where bark had been shaded broods had largely developed to new adult stage.

It was found that conditions in this tree corresponded closely to that in a number of other trap trees on the area where infested bark had been left under similar conditions. Wherever the bark had been exposed to direct sunlight during the heat of the day all broods in an immature condition were dead or in a discolored condition showing no evidence of vitality. It was noted that when the bark had been placed with the surface tilted so as to be at direct right-angle to the suns rays at midday and

where sunlight was unbroken for several hours this devitalized condition of the broods was apparent within two or three days.

2. Climatic Conditions.

In the immediate locality of the Sequoia National Park where these experiments were carried on elevation of the infested trees ranged from 5,000 to 6,000 feet. Complete and official weather records are not available for the season of 1919. Occasional records, however, indicated that maximum summer temperatures in the shade rarely exceeded 95 degrees F. and that the minimum temperatures at night were usually above 40 degrees F. Long periods of dry, cloudless, weather prevailed however, which rendered it possible to expose the bark to a maximum period of sunlight daily and with few interruptions from May 1st to October 30th.

3. Relation of percent of Mortality to conditions of Exposure of Infested Bark.

During the latter part of August the writer spent several days on the area and outlined the following checks to determine

the degree of mortality which may result under vaying conditions of exposure of the infested bark.

From six infested trees a series of 27 bark sections averaging 1 and $\frac{1}{2}$ sq. ft. each were selected and were exposed under the following conditions:

Check No. 1. 12 sections were removed from logs and placed with inner bark surface upward on ground in positions exposed to direct sunlight.

Check No. 2. 8 sections were removed from logs and placed, with outer bark surface upward, on the ground in positions exposed to direct sunlight.

Check No. 3. 7 sections not exposed to direct sunlight, of which 3 were left undisturbed on under side of log, 2 were left undisturbed on upper side of log, and 2 sections were removed and placed under shaded side of log with inner bark surface upward.

These bark sections were placed in position during July and August. Toward the close of the season they were collected and shipped to the laboratory at Ashland, Oregon. where a detailed examination was made to determine the degree of mortality resulting

in each check. Records were made of the following in each individual bark section.

1. Length of egg galleries;

   This indicates the initial quantity of infestation in each section as the number of eggs deposited is in direct proportion to the length of gallery extended.

2. Total number of ventilation holes:

   These were marked and counted in order to seperate them from exit holes in the same bark section.

3. Total number of exit holes:

   Each exit hole represented the emergence of one new adult beetle and their total (when seperated from ventilation holes) indicates the number of new adults which developed in and successfully emerged from each bark section*.

Footnote:

* It has long been known that adults emerge from the bark on the side exposed to the greatest amount of light. When the bark is in its normal position on the tree, the exit holes therefore occur on the outer surface. If the bark is removed and placed with inside surface toward the light, the direction of emergence is reversed

and exit holes will accordingly occur only on the inner surface. The exit holes counted in these checks were found on either the inner or the outer surface according to the position in which the bark was exposed.

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4. Total number of dead individual larvae, pupae or new adults found within the bark*.

Footnote.

* This was arrived at by working the bark down with a plane, removing it in successive layers about 1/32 of an inch in thickness. The larval mines and chambers in the outer bark were uncovered by this process without destroying either dead or living individuals of the broods occupying them. Larvae, pupae and new adults as they were uncovered, were collected and counted for each section.

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5. Total number of living individual larvae, pupae and new adults in the outer bark.

From the records of this analysis it is possible to compare the number of dead individuals found in the outer bark, with the number of living individuals, both those remaining in the outer bark and those which the exit holes indicated had successfully

developed and emerged. This comparison determines the approximate total mortality which occured after the broods had reached the larval stage in the outer bark. Mortality which may have occurred during the egg or very early larval stage is not taken into consideration, for as has been shown, infested bark can not be readily removed from the logs until the brood has advanced beyond these initial stages, and in control operations therefore the egg and early larval stages are seldom treated. The percentages of mortality determined also fail to take into account the individuals which may have been eaten by predatory larvae. The very small number of predatory larvae found in the bark sections examined however indicates that they affect but a very low percent of the brood.

The percentages of mortality which are shown below represent only dead individuals found in the outer bark which were killed apparently from conditions arising from the nature of exposure of infested bark.

TABLE No. L.

ANALYSIS OF BROOD MORTALITY IN INFESTED BARK AFTER EXPOSURE TO SUN

Removed from log and placed on ground with inside surface upward

Tree No.	C11T	C11T	C98	C98	C45T	C45T	C64	C31T	C31T	C51T	C13	C13
Bark section No.	b-2	b-3	a-1	a-2	b-3	b-4	b-2	b-3	b-4	b-5	a-1	a-2
Bark surface, sq. inches	220	180	209	240	220	200	180	112	180	162	180	220
Egg galleries, "	132	228	228	204	168	156	128	132	204	216	210	174
Ventilation holes	12	20	18	20	16	19	10	16	20	15	23	25
Bark removed from log	July 17	July 17	Aug 30	Aug 30	Aug 27	Aug 27	Aug 28	Aug 4	Aug 4	Aug 4	July 11	July 11
Condition of brood when removed	larvae 4/4 first pupae	larvae 4/4 first pupae	larvae 1/2-3/4 first pupae " adults	larvae 1/2-3/4 pupae first adults	larvae 4/4 pupae first adults	larvae 4/4 pupae first adults	eggs larvae 0-1/2	larvae 1/2-4/4	larvae 1/2-4/4	larvae 1/2-4/4	larvae 4/4 first pupae	larvae 4/4 first pupae
Bark sections collected	Aug. 30	Aug. 30	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Aug. 30	Aug. 30	Aug. 30	Sept. 29	Sept. 29
No. days exposure to sun	44	44	45	45	48	48	47	26	26	26	70	70
Period of examination	Nov. 15-30	Nov. 15-20	Nov. 15-30	Nov. 15-30	Dec. 1-15	Dec. 1-15	Dec. 1-15	Dec. 1-15	Dec. 1-15	Dec. 1-15	Dec. 1-15	Dec. 1-15
Data from bark analysis D. brevicomis	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead	alive / dead
larvae	222	280	274	256	136	94	216	135	236	257	153	371
pupae	16	21						28	12	3	301	34
new adults	111	6			38	41		19	7	1	2	
exit holes	1				92	66		1				6
totals	1 / 349	307	274	256	92 / 174	66 / 135	216	1 / 182	249	261	456	6 / 405
mortality percent	99.2%	100. %	100. %	100. %	65.%	67. %	100. %	99. %	100. %	100. %	100. %	98.6%
predaceous larvae	2			4	3	4	2	3		3	1	

TABLE No.2.

ANALYSIS OF BROOD MORTALITY IN INFESTED BARK AFTER EXPOSURE TO SUN

Removed from log and placed on ground with outside surface upward

Tree No.	C11T		C98		C98		C45T		C45T		C64T		C31T		C31T	
Bark Section No.	a-1		b-3		b-4		a-1		a-2		a-1		a-1		a-2	
Bark surface, sq.inches	200		180		220		220		220		180		198		144	
Egg galleries, "	84		192		228		180		120		136		144		120	
Ventilation holes	3		17		20		16		12		18		19		16	
Bark removed from log	Jul. 17		Aug. 30		Aug. 30		Aug. 27		Aug. 27		Aug. 28		Aug. 4		Aug. 4	
Condition of brood when removed	larvae 4/4 pupae		larvae ½-4/4 pupae 1st adults		larvae ½-4/4 pupae 1st adults		larvae 4/4 pupae 1st adults		larvae 4/4 pupae 1st adults		eggs larvae 0-½		larvae ½-4/4		larvae ½-4/4	
Bark sections collected	Aug. 30		Oct. 15		Oct. 15		Oct. 15		Oct. 15		Oct. 15		Aug. 30		Aug. 30	
No days exposure to sun	44		46		49		49		49		48		26		26	
Period of examination	Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15	
Data from bark analysis																
D. brevicomis	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead
larvae		154	8	211	5	182		79		56		183		80		71
pupae		4												25		30
new adults		2	19	17	10	5		19		22				171		33
exit holes			5		1		152		104		1		37		5	
totals		160	32	228	16	187	152	98	104	78	1	183	37	276	5	134
mortality percent	100.%		95.%		92.1%		35.2%		42.5%		99.5%		85.%		96.4%	
predaceous larvae					3		6		3	2				3		

TABLE No.3.

ANALYSIS OF BROOD MORTALITY IN BARK SECTIONS LEFT UNDISTURBED ON LOG, OR REMOVED AND PLACED IN SHADED POSITION.

	undisturbed on under side of log						undisturbed on upper side of log				removed, placed in shade of log, inner surface upward			
Tree No.	C31T		C31T		C31T		C98		C98		C13		C13	
Bark section No.	c-6		c-7		c-8		c-5		c-6		b-3		b-4	
Bark surface, sq. inches	144		162		140		198		218		218		200	
Egg galleries, "	192		144		144		156		180		244		186	
Ventilation holes	20		22		17		21		22		25		7	
Tree was felled	July 1		July 1		July 1		Aug. 30		Aug. 30		July 11		July 11	
Condition of brood when felled	larvae ½-¾		larvae ½-¾		larvae ½-¾		larvae ½-¾ 1st pupae " adults		larvae ½-¾ 1st pupae " adults		larvae ¾ 1st pupae		larvae ¾ 1st pupae	
Bark sections collected	Aug. 30		Aug 30		Aug. 30		Oct. 15		Oct. 15		Sept. 29		Sept 29	
No. days exposure	60		60		60		45		45		49		49	
Period of examination	Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15		Dec. 1-15	
Data from bark analysis														
D. brevicomis	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead
larvae				2		6	73		66	16		14		14
pupae														5
new adults						1	11	1	2			1		2
exit holes	128		80		90		31		39		332		241	
totals	128		80	2	90	7	115	1	107	16	332	1	241	21
Mortality percent	-		4.7%		7. %		.9%		13. %		.3%		8. %	
Predaceous larvae							4		3	2				

Summary of Data:

Check No. 1 - Detailed data in Table No. 1.

Number of bark sections 12

Total Surface, square inches, ... 2303

(Removed from log and placed on ground with inner bark surface exposed to the sun).

	Living	Dead
No. of larvae found after exposure		2630
No. of pupae found after exposure		415
No. of new adults found after exposure		269
Successful emergence, (exit holes)	166	
Totals	166	3264

Total mortality 94.6%

Average mortality of 12 sections 94.6%

Check No. 2 - Detailed data in Table No. 2.

Number of bark sections 8

Total Surface, square inches, ... 1572

(Removed from log and placed on ground with outer bark surface exposed to the sun).

	Living	Dead
No. of larvae found after exposure	13	1016
No. of pupae found after exposure		59
No. of new adults found after exposure	29	269
Successful emergence, (exit holes)	305	
Totals	347	1344
Total mortality		79.47%
Average mortality		80.96%

Check No. 3 - Detailed Data in Table No. 3.

Number of bark sections 7

Total surface, square inches, ... 1280

(Not exposed to direct sunlight, sections being left undisturbed on upper or lower side of log, or removed and placed in totally shaded positions).

	Living	Dead
No. of larvae	139	52
No. of pupae	0	0
No. of new adults	13	5
Successful emergence, (exit holes)	941	
Totals	1093	57
Total mortality		4.95%
Average mortality of 7 sections		4.8% *

Footnote.

* The highest mortality in this check was 13% found in the two sections left undisturbed on the upper side of the log which received a limited amount of sun during the day.

Theses results indicate:

1 - That if infested bark is left on the log or removed and placed in shaded positions, broods emerge successfully, the resultant mortality being little if any above normal and not sufficient to appreciably reduce the infestation.

2 - That if infested bark is removed from the log, placed in positions where it is exposed to direct sunlight for a considerable period, a high mortality occurs which affects the broods in all stages of development. The mortality is highest when the bark is exposed with the inner surface of the bark to the sun, the outer surface of the bark being next the ground. The mortality which results from the proper exposure of infested bark under these conditions may average as high as 95% and is

sufficient to effectively reduce the infestation.

4. - Probable Cause of Mortality.

A large series of the dead individuals representing larvae, pupae and new adults, were selected from the material found in the examination of this exposed bark and forwarded to Dr. A.D. Hopkins at Washington, D.C. At his request the specimens were examined by Mr. A.T.Speare, Mycoentomologist of the Bureau of Entomology, for possible evidence of fungus parasitism.

Mr. Speare reported as follows:

"In reference to your memorandum of Jan 5, 1920, and specimens of Dendroctonus brevicomis from J.M.Miller, of Ashland, Oregon. will say that I have examined the latter and find absolutely no sign of fungus parasitism. Examination of the material as it was sent and of many individuals that were placed under suitable conditions to induce a growth of parasitic fungus, if present, have failed to show any fungus organism that could possibly be associated with the death of the insects".

Obviously the cause of the mortality is due to the fact that the broods cannot survive the temperatures which are produced in bark exposed to the sun. These temperatures, as

will be shown later, are much higher than the corresponding air temperatures and are considerably higher than the temperatures which occur in bark in its normal position on either the shaded or sunny side of standing, infested, trees. The killing of wood or bark infesting insects by exposure of the infested material to sunlight, has been a matter of previous observations; Mr. F.C. Craighead, of the Bureau of Entomology, originally developed the effectiveness of seasoning logs in the sun as a means of destroying wood boring larvae. Where experiments were carried out in Arizona it was found that two weeks exposure were sufficient to kill practically all insects.

It has been frequently noted that where an infested tree is felled so that the prostrate trunk lies directly exposed to the sun during the midday period, broods do not emerge successfully on the upper part of the log, although normal emergence may occur on the under shaded surface.

Humidity is recognized as a factor modifying to an appreciable extent the influence of temperatures on insect development and mortality. In the case of the western pine beetle the broods at time of exposure are encased within the dry outer bark which undoubtedly modifies to some extent the direct effect of the relative atmospheric humidity. In the contemplation of exposure of infested bark to sunlight as a means of destroying the broods of this beetle, it is evident that humidity is a factor that cannot in any way be controlled in field tests. If this method is to be successful in control work the temperatures produced by exposure to the sun must be high enough to effectively kill the broods regardless of the varying degree of atmospheric humidity or moisture content of the outer bark.

5. - Data Not Available From Present Field Records.

The following points were not determined during the course of the 1919 field investigations:

1. Minimum temperatures which must be reached or maintained in the

bark in order to result in effective killing of the western pine beetle.

2. Minimum air temperatures during midday which will result in corresponding killing temperatures in the bark which is exposed to the sun.

3. Period of exposure which is necessary to produce effective mortality under low or high killing temperatures.

4. Season of year during which climatic conditions prevail that will make possible exposure of infested bark in the sun under effective killing temperatures.

Information on all these points is essential to intelligent application of this method in actual control work. As the results of sun exposure were not discovered until late in the season it was impractical to arrange the equipment and personnel for carrying out adequate field tests during the season of 1919. This work, however, is planned in detail for 1920.

Laboratory and local field experiments however, carried out at Ashland, Oregon, during the winter season of 1919-1920,

have developed considerable data bearing directly upon the first three points outlined above.

II. - LABORATORY TESTS INDICATING CRITICAL TEMPERATURES WHICH PRODUCE MORTALITY OF LARVAE.

1. - Methods Employed.

The series of tests carried out in the laboratory were designed to determine the degree of mortality which will result from exposure of Dendroctonus brevicomis broods to artificial temperatures corresponding to those which may be expected to occur in bark exposed to sunlight under filed conditions.

The material used in these tests consisted of bark sections containing overwintering broods mainly in the advanced larval stage. These sections were subjected in the laboratory to temperatures ranging from 40 to 130 degrees F. by means of exposing them at varying distances from a heating stove.

The bark sections were arranged with inner bark surface facing the heater, the outer surfaces placed against a wooden

frame. Mercurial thermometers which had been tested and compared were used for recording the temperatures. Stirring rod themometers, designed for testing the temperatures of photographic solutions, were used for testing the temperature of the infested bark. For each lot of bark sections tested a thermometer was permanently imbedded in the bark by boring a hole, just large enough to contain the thermometer, in one end of a bark section of average thickness. The thermometer was imbedded paralell to the surface of the inner bark at about the depth where most of the pupal cells, formed by the over winter larvae, occur. This apparatus is illustrated in Plate 2, B.

In each test corresponding ~~temperatures~~ records were also kept of the air temperature in the room some distance from the heater. Beginning in the morning when temperatures of the bark and room were nearly equal, (usually about 40 degrees F.), the temperature of the bark was raised during the day to a point previously determined and maintained as long as desired. When the test was

continued during the second day the artificial heat was discontinued at night and the bark and room were both cooled down to normal air temperatures.

After completion of the test* the bark sections were kept under ordinary laboratory temperatures of 40 to 70 degrees F. for several days and were then subjected to the same examination and analysis as that applied to field checks, described

on page 8 .

Footnote:

* Considerable difficulty was at first experienced in maintaining and controlling even temperatures with this apparatus, and in all 4 attempts were made before satisfactory control was arrived at by keeping the bark at greater distances from the heater and maintaining higher room temperatures. In some of the first tests it was noted that considerable variation in the degree of mortality occurred which did not consistently correspond to the advance of temperature during the early periods of exposure. In a measure this was accounted for by the position of the individual larvae in the bark. Where larvae were relatively near the inner

surface, mortality would be high, while among individuals well imbedded in the center of the bark or near the outer surface away from the heater, the mortality was low. After a long period of exposure extreme variation was not found, the mortality being fairly uniform and consistent. However, it is evident that the apparatus did not provide for exactly uniform temperatures in all bark sections.

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2. - Effect of Artificial Temperatures Upon Larvae in the Outer Bark.

Test No. 1 - Jan 5 and 6, 1920. (Lot 11).

Purpose - To determine effect of temperatures ranging from 40 to 110 degrees F. upon Dendroctonus brevicomis larvae in the outer bark.

Twenty-three infested bark sections, totaling 2128 square inches, were used as a basis. Three sections were set aside as a check /under ordinary laboratory temperatures ranging from 40 to 70 degrees F. The remaining twenty sections were then subjected to slowly increasing temperatures. Beginning at 55 degrees F. on the morning of the 5th, the temperature of the bark was increased until at the end of 6 hours it had reached 110 degrees F. One bark

section was removed from the test at each thirty minute interval and kept under ordinary temperatures until examined. Corresponding temperatures of bark and room were recorded at 15 minute intervals. Artificial heat was discontinued at 4:30 PM and the test was resumed along the same line the following day and continued until all bark sections had been removed.

The results as shown by analysis of the bark sections are given in Table No. 4. They are also shown in diagramitic form in Fig. No. 1. It is apparent that after a temperature of 110 degrees F. had been reached, but not exceeded, the mortality averaged 97%, and that some mortality had occurred by the time a temperature of 100 degrees F. had been reached. The test was repeated a second time with practically the same result.

Test No. 2 - Jan 6 to 11, 1920. (Lot 12).

Purpose - To determine the effect of sustained bark temperatures ranging from 40 to 100 degrees F. upon Dendroctonus brevicomis larvae in the outer bark.

A series of 25 infested bark sections, totaling 1863 square inches, were used, one being kept aside as a check, the

TABLE No.4

Lot. 11

Date	Hour	Temperature Fahr. air (room)	Temperature Fahr. infested bark	Bark section No. removed No.	Bark section No. removed surface sq.in.	Condition of brood after exposure No. individual larvae living	Condition of brood after exposure No. individual larvae dead	Mortality percent
1920				3				
Jan.5	9:45am	78	56	cheks	520	573	-	0
	10:00	80	64					
	10:30	84	74					
	11:00	80	80					
	11:30	94	92	a	108	53	13	19.9%
	12:00m	94	99	b	82	7	38	84.4 %
	12:30pm	92	98	c	84	7	93	93.%
	1:00	90	98	d	75	13	52	78.7%
	1:30	90	94	e	96	60	62	50.8
	2:00	88	100	f	82	-	122	100.%
	2:30	92	105	g	70	6	46	88.4%
	3:00	93	105	h	96	29	61	67.7%
	3:30	93	106	i	75	51	43	45.7%
	4:00	95	103	j	63	29	63	68.4%
	4:30	96	110	k	75	5	43	89.7%
Jan.6	8:15am	42	40					
	8:30	65	60					
	9:00	88	98	l	82	4	49	92.4 %
	9:30	86	100	m	77	-	77	100. %
	10:00	94	102	n	70	-	88	100. %
	10:30	92	103	o	80	-	15	100. %
	11:00	90	105	p	75	-	66	100. %
	11:30	96	108	q	70	-	68	100. %
	12:00m	92	105	r	80	-	82	100. %
	12:30pm	94	106	s	88	9	86	90.5 %
	1:00	88	99	t	80	11	82	88.1 %

Labratory Test. No.1. Effect of temperatures ranging from 40 to 110 degrees upon D.brevicomis larvae in the outer bark.

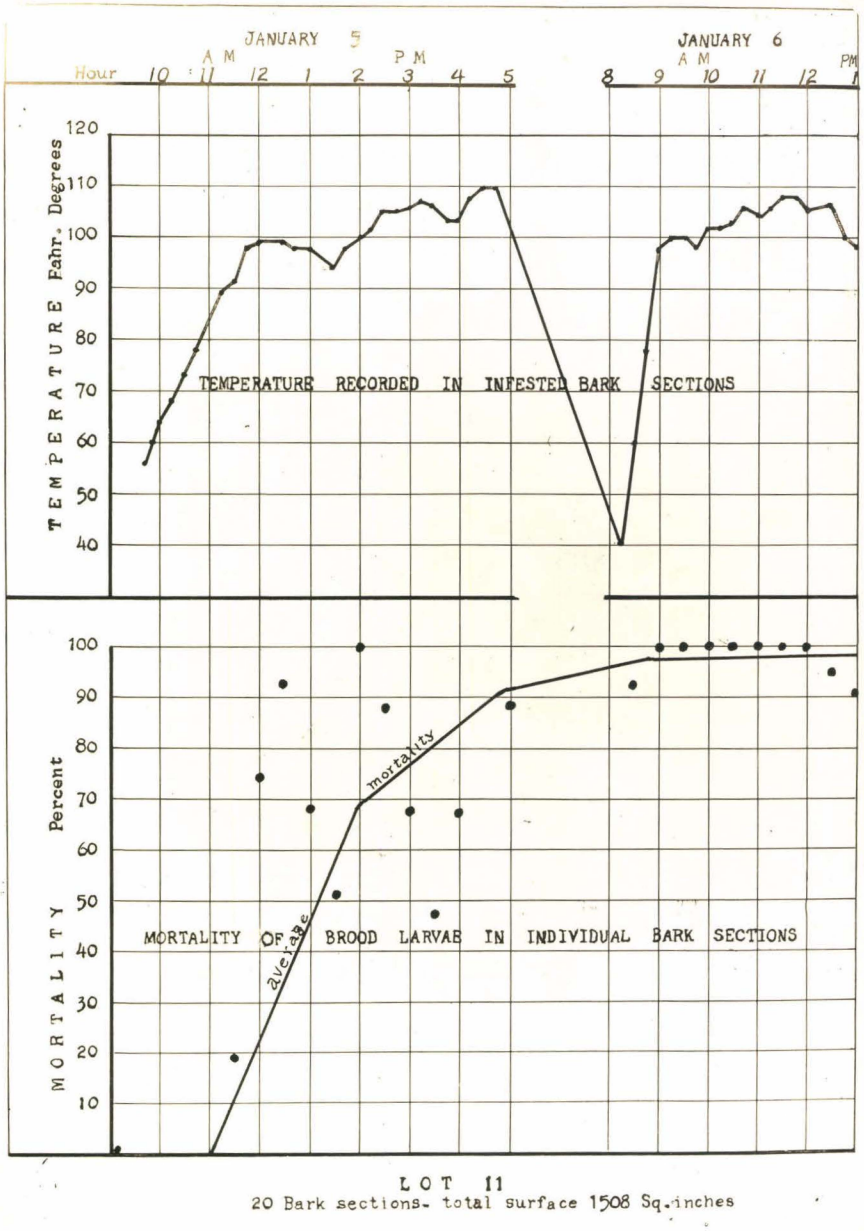


FIG. No. 1 - Chart showing mortality of Dendroctonus brevicomis larvae exposed in outer bark to temperatures ranging from 40 to 110 degrees Fahr.

remaining 24 sections were exposed to daily maximum temperatures of 90 to 100 degrees F., and allowed to cool down to normal air temperatures during the night. The experiment was started at 2: PM, on January 6th and closed at 5: PM January 11th, involving 5 and ½ days. The methods were identical to those described for lot 11 except that maximum temperatures were mainatained between 95 and 100 degrees F., so far as possible and the bark sections were removed at much longer intervals, no more than 4 being removed on any one day except at the close of the experiment. During the last two days, due to failuer of control, the temperatures on two occasions reached a few degrees above 100 F. The records are given in Table No. 5, and are shown diagramatically in text Fig. No. 2. These show that a low but variable degree of mortality occurred after the first day's exposure, the average slowly increasing thruought the experiment. At the close of the experiment the average mortality in 8 sections removed was 45.4%. The results are unsatisfactory due to the failure to maintain

TABLE No.5
(Lot 12)

Date	Hour	Temperature Fahr. air (room)	Temperature Fahr. infested bark	Bark section removed No.	Bark section removed surface sq.in.	Condition of brood after exposure No.individual larvae living	Condition of brood after exposure No.individual larvae dead	Mortality percent
1920								
Jan.6	2:00pm	84	65	check	180	161		0
	3:00	90	88					
	4:00	92	94					
	4:30	90	90	a	80	41		0
Jan.7	8:30am	58	52					
	9:30	74	83					
	10:00	84	93	b	99	118		0
	11:00	84	98					
	12:00m	85	93	c	72	67	1	1.6 %
	1:00pm	88	94					
	2:00	90	98	d	96	161	4	2.4 %
	3:00	93	98					
	4:00	85	90	e	75	93	-	0
Jan.8	9:00am	65	74					
	11:00	80	96					
	12:00m	78	92					
	1:00pm	80	90	f	96	126	2	1.5 %
	2:00	74	82					
	3:00	88	96	g	67	35	2	5.4 %
	4:00	90	98					
	4:30	88	98	h	90	63	18	22.2 %
Jan.9	8:00am	40	37					
	10:00	90	98					
	12:00m	82	98	i	54	85	13	46.4 %
	1:00pm	78	88					
	2:00	82	90					
	3:00	88	99	j	88	29	20	40.8 %
	4:00	88	100					
	4:30	86	100	k	70	20	10	33.3 %
Jan.10	8:00am	38	36					
	10:00	76	92					
	11:00	85	102					
	12:00m	78	92	l	48	14	2	12.5 %
	1:00pm	84	90					
	2:00	80	92					
	3:00	80	92	m	72	63	37	37.3 %
	4:00	85	94					
	4:30	86	92	n	72	17	7	29.1 %
Jan.11	8:00am	34	34					
	11:00	85	102					
	1:00pm	82	92	o	72	60	13	17.8 %
	3:00	88	96					
	4:15	90	103	p				
				tp	712	442	321	45.4 %
				x				

Labratory Test.No.2. Effect of continued exposure to bark temperatures ranging from 40 to 103 degrees upon D.brevicomis larvae in the outer bark.

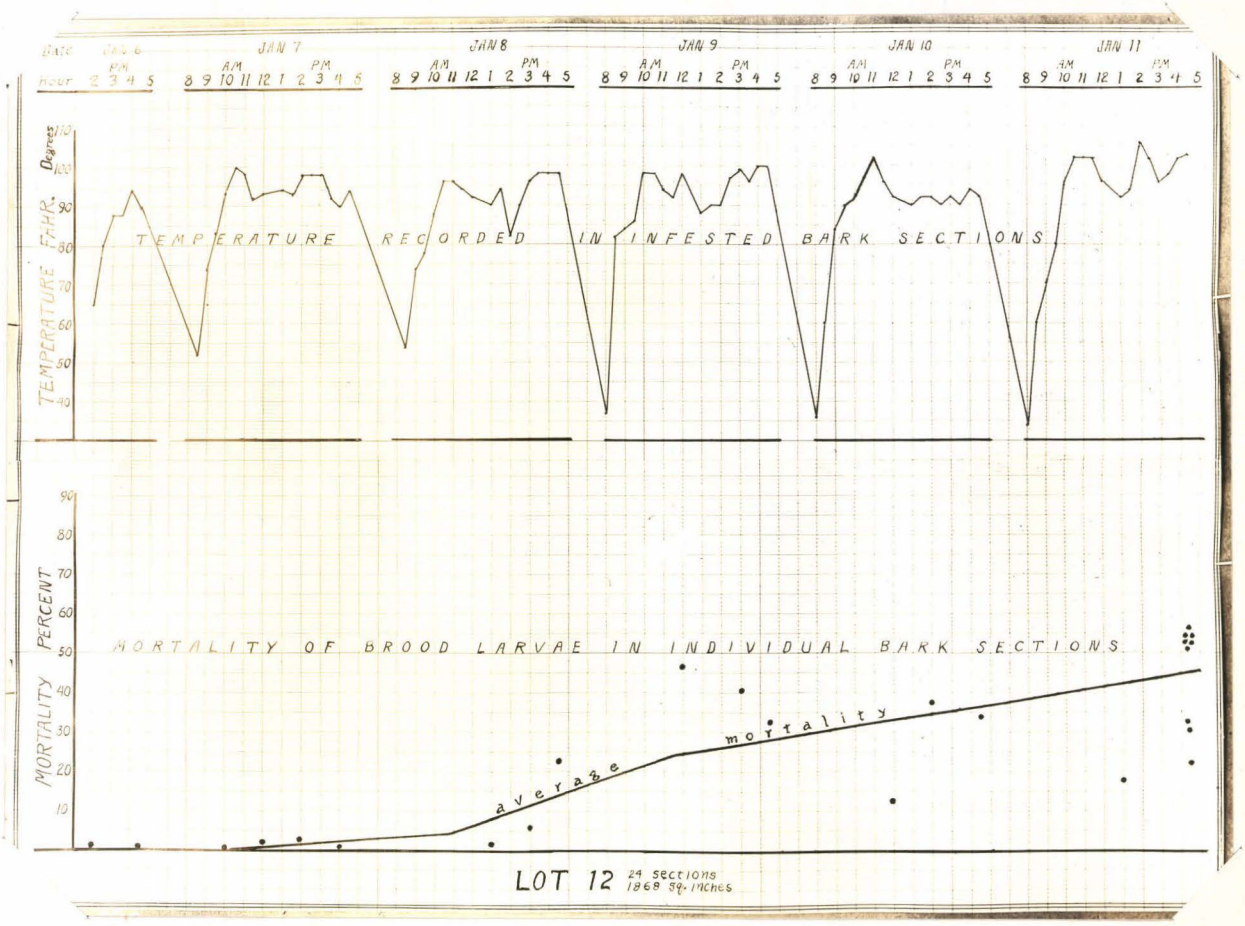

DATE JAN 6 JAN 7 JAN 8 JAN 9 JAN 10 JAN 11
HOUR PM 3 4 5 AM 8 9 10 11 12 1 2 3 4 5 PM AM 8 9 10 11 12 1 2 3 4 5 PM AM 8 9 10 11 12 1 2 3 4 5 PM AM 8 9 10 11 12 1 2 3 4 5 PM AM 8 9 10 11 12 1 2 3 4 5 PM AM 8 9 10 11 12 1 2 3 4 5
TEMPERATURE FAHR. Degrees
110
100
90
80
70
60
50
40
TEMPERATURE RECORDED IN INFESTED BARK SECTIONS
MORTALITY PERCENT
90
80
70
60
50
40
30
20
10
MORTALITY OF BROOD LARVAE IN INDIVIDUAL BARK SECTIONS
average mortality
LOT 12 29 sections 1868 Sq. Inches

FIG. No. 2 - Chart showing mortality of Dendroctonus brevicomis larvae in outer bark under continuous exposure to temperatures from 40 to 103 degrees Fahr.

even control of temperatures with the apparatus, but they indicate that mortality does occur if exposure is maintained long enough, when the maximum temperature ranges from 90 to 102 degrees F.

Tset No. 3 - January 21, 1920. (Lot 14).

Purpose - To Determine the effect of bark temperatures raised slowly from 50 to 130 degrees at an average rate of 10 degrees per hour, upon Dendroctonus brevicomis larvae in the outer bark.

It was considered that this test would determine the limits of the range of critical temperatures, by indicating under brief exposure the minimum point where the first mortality is appreciable, and the maximum point where complete mortality results.

Sixteen bark sections, totaling 1045 square inches, were used as a basis for this test, 2 sections being used as a check. Beginning at 9:AM January 21st, the bark temperatures was slowly and gradually increased from 40 degrees F. until it reached a maximum of 130 degrees F. at 4: PM. Fairly satisfactory control of the temperature was arrived at by maintaining a relatively higher room temperature and keeping the sections further away from

the heater. Bark sections were removed at 30 minute intervals throughout the experiment. The data shown in Table No. 6 and in Fig. 3 are the most satisfactory of any arrived at, as undue variation, either in the temperature or resultant mortality of the larvae was not experienced. The first mortality (44%) was recorded in the section removed when a temperature of 106 degrees F. had been reached. In the following section, removed at 110 degrees F., a mortality of 96.8% had been reached while at 114 degrees F., 30 minutes later, 100% mortality had resulted. No larvae at all were found to have survived after the temperature reached this point.

Tests Nos. 1, 2, and 3, all indicate that a range of critical temperatures beginning at a point between 95 and 100 degrees F. and extending to a point between 110 and 115 degrees F. affect the larvae of Dendroctonus brevicomis in the outer bark, so as to induce mortality, and that no larvae can survive when exposed to temperatures exceeding the maximum of this range.

T A B L E No.6
(Lot 14)

Date	Hour	Temperature Fahr: air (room)	infested bark	Bark Sections removed: No.	surface sq.in.	Condition of brood after exposure: No.individual larvae alive	dead	Mortality percent
1920								
Jan.21	9:15am	50	40	a	80	172	-	0
	9:30	63	60					
	9:45	66	68					
	10:00	72	78	b	64	62	-	0
	10:15	76	82					
	10:30	78	85	c	54	36	-	0
	10:45	78	86					
	11:00	80	86	d	72	143	-	0
	11:15	82	87					
	11:30	89	89	e	60	184	-	0
	11:45	90	90					
	12:00m	92	90	f	72	219	-	0
	12:15pm	93	90					
	12:30	94	92	g	81	132	-	0
	12:45	99	96					
	1:00	101	100	h	63	94	-	0
	1:15	101	102					
	1:30	103	106	i	63	74	58	44. %
	1:45	106	108					
	2:00	106	110	j	77	4	124	96.8 %
	2:15	106	112					
	2:30	108	114	k	60	-	55	100. %
	2:45	106	115					
	3:00	107	118	l	60	-	63	100. %
	3:15	110	124					
	3:30	110	128	m	63	-	186	100. %
	3:45	112	128					
	4:00	110	128	n	80	-	209	100. %
	4:15	110	128					
	4:30	108	130	o	54	-	54	100. %
	4:45	104	128					
	5:00	100	126	p	42	-	70	100. %

Labratory Test No.3. Effect of bark temperatures rising slowly at an average rate of 10 degrees per hour upon D.brevicomis larvae in the outer bark.

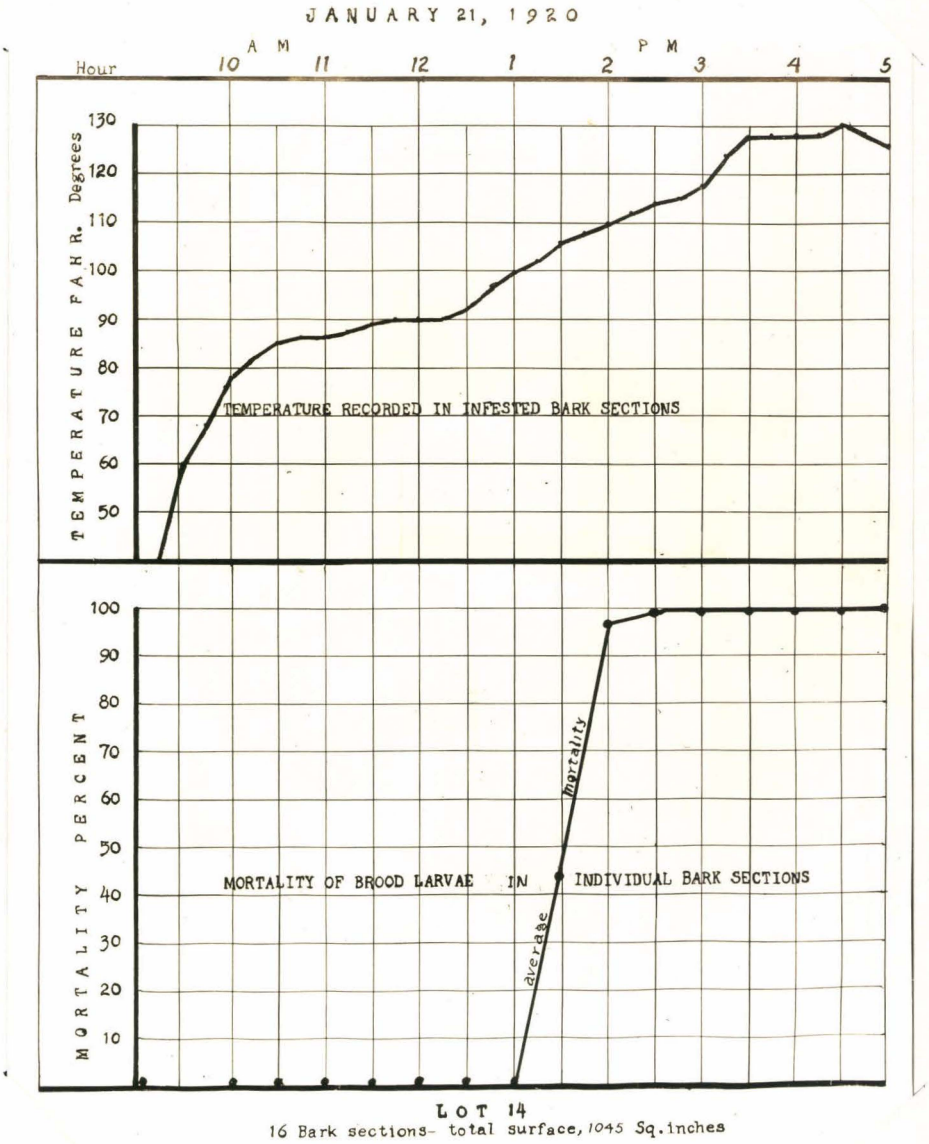


FIG. No. 3 - Chart showing mortality of Dendroctonus brevicomis larvae in outer bark under temperatures rising from 50 to 130 degrees at an average rate of 10 degrees per hour.

As has already been indicated, the relative atmospheric humidity probably does not correspond to that which the larvae experience in the outer bark. As the apparatus was not available for determining this point no effort was made to correlate the relation of relative atmospheric humidity to the effect of bark temperatures upon the larvae.

A wet and dry bulb thermometer, loaned by the local representative of the U.S. Weather Bureau, was placed in the room used for these tests and occasional records taken. It was noted that at air temperatures ranging from 50 to 70 degrees F., the relative humidity ranged from 80 to 75 degrees. As the air temperatures were increased during the tests, this humidity decreased. At a temperature of 110 degrees F. in the room the humidity approximated 38 to 40%. The immediate mortality which occurred in all tests after the temperature reached a point above 110 degrees F. indicates, however, that any variation in atmospheric humidity did not influence by more than a few degrees the effect of the temperatures upon the larvae.

3. - Effect of Artificial Air Temperatures Upon Larvae Removed From the Outer Bark.

In all of the field and laboratory tests which have been described the broods ~~examined~~ were concealed in the outer bark at the time of exposure to critical temperatures. As they were not removed and examined until some time after this exposure the immediate effect of these temperatures upon the larvae could not be observed.

When living normal larvae are removed from the outer bark and kept in wood or paper receptacles, exposed to the air under ordinary temperatures but protected from sunlight, they will remain active and apparently healthy for periods varying from 10 to 20 days. In order to observe the immediate effect of critical temperatures upon the larvae, further experiments were carried out along the following lines.

Normal, uninjured larvae were removed from the outer bark and placed in a series of open pasteboard recepatcles. In order to expose them to the desired temperatures, a glass battery jar,

14 inches deep and 10 inches in diameter was used. This was suspended by means of a stand over an electric disc which had a controlling switch regulating the degree of heat at three fixed points. The jar was covered with a soft pine board. It was found that when the temperature of the electric disc was fixed at a constant point under a uniform room temperature the air temperature within the jar could be regulated at will at points between 70 and 120 degrees F., by elevating or lowering the jar at fixed distances above the disc. This gave satisfactory and accurate control as it was possible to increase or lower the temperature at a constant rate, or to maintain any given temperature for an indefinite time. The control was not automatic however but required continual attention.

Small pasteboard pill boxes without covers were used to contain the larvae. These were placed within the jar upon a wire screen mesh which rested upon wooden supports so as to prevent the screen from touching the sides of the jar at any point. The thermometer used for recording temperatures was suspended

within the jar so that the bulb was just above the exposed larvae. The apparatus is shown in Plate 2, A.

Larvae just freshly collected from the bark were used for all tests. After exposure to the desired series of temperatures, they were removed from the jar and kept under ordinary laboratory temperatures for a period to watch for any possible recovery, but final mortality was determined within 24 hours after the test.

Test No. 4 - February 13, 1920.

Object - To determine the effect of temperature rising from 70 to 120 degrees F. at rate of 10 degrees per hour upon Dendroctonus brevicomis larvae removed from the outer bark and exposed to the air within the laboratory.

Basis: 400 larvae selected from well developed individuals of an overwintering brood. These were divided into 16 lots of 25 larvae each, contained in seperate pill boxes, which were placed within the container.

Double space

Beginning at 12:30PM, the temperature was raised gradually from 70 degrees F. until it reached 117 degrees F. at 5: PM. The first lot of larvae were removed at 1:PM at a temperature of 80

degrees F. From this point on until the close of the experiment one lot of larvae were removed at each 15 minute interval. The records resulting from this test are shown in Table No. 7, and in Fig. 4.

In this test the effort was made to duplicate the same range of temperatures and period of exposure as that followed in Test No. 3, when the larvae were in the outer bark. The results are also very closely duplicated, except that the mortality of the exposed larvae occurred at slightly lower temperatures than those in the bark. The same period of critical temperatures between 95 and 115 degrees F. however is indicated by both tests, but 110 degrees F. seems to be the maximum which exposed larvae cannot survive.

Test No. 5 - February 9, 1920.

Purpose - To determine period of time necessary to produce complete mortality of Dendroctonus brevicomis larvae which have been removed from the bark and exposed to constant air temperature of 105 degrees.

Basis: 200 larvae were divided into 8 lots of 25 each.

TABLE No.7

Date	Hour	Temperature Fahr. air room	air container	Lot. No. removed	Condition of larvae after exposure living	dead	Mortality: percent	Notes on larvae when first removed from exposure
1920 Jan. 13	12:30pm	70	70					
	12:45	74	75					
	1:00	88	80	a	25	-	0	normal activity
	1:15	78	85	b	25	-	0	normal activity
	1:30	76	90	c	25	-	0	activity increases
	1:45	80	93	d	25	-	0	" "
	2:00	80	95	e	25	-	0	maximum activity
	2:15	80	98	f	25	-	0	activity decreases
	2:30	81	100	g	24	1	4. %	all dormant
	2:45	82	102	h	23	2	8. %	" "
	3:00	84	104	i	22	3	12. %	" "
	3:15	84	106	j	22	3	12.%	" "
	3:30	86	108	k	16	9	36. %	" "
	3:45	86	110	l	-	25	100. %	discoloring
	4:00	88	112	m	-	25	100. %	"
	4:15	89	114	n	-	25	100. %	"
	4:30	88	116	p	-	25	100. %	"
	4:45	82	118	p	-	25	100. %	"

Labratory Test No.4. Effect of temperatures rising from 70 to 118 degrees at rate of 10 degrees per hour upon D.brevicomis larvae removed from the outer bark and exposed to the air within the labratory.

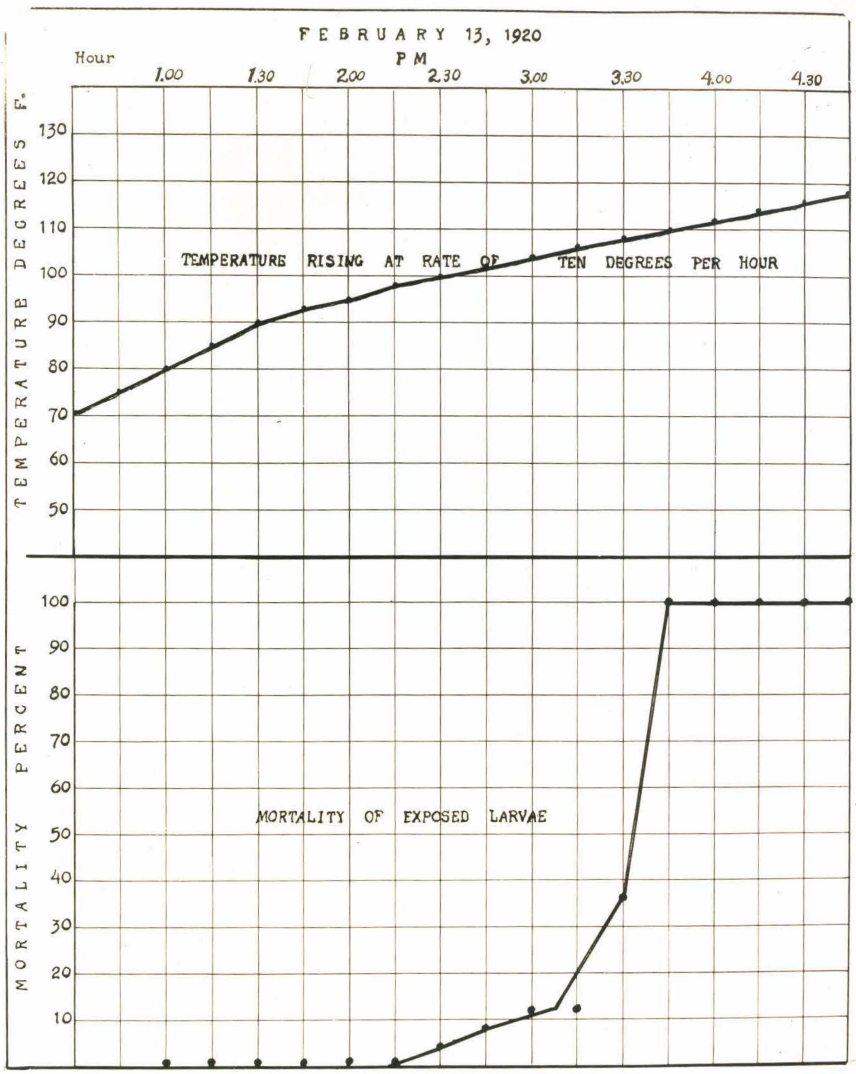


CHART SHOWING MORTALITY OF D.BREVICOMIS LARVAE, REMOVED FROM BARK AND EXPOSED TO TEMPERATURES BETWEEN 70 AND 120 DEGREES Fahr.

FIG. No. 4 - Chart showing mortality of Dendroctonus brevicomis larvae removed from the outer bark and exposed to temperatures rising from 70 to 118 degrees F.at rate of 10 degrees per hour.

Beginning at 9: AM the temperature was raised from 65 degrees F. to 105 degrees F. by 10: AM. It was then maintained at this point until 12:30 PM. Lots were removed at 95, 100, and 105 degrees F., and at each 30 minute interval during remainder of exposure.

It was found that 24% mortality occurred by the time that 105 degrees F. was reached, and during the next 30 minutes interval the mortality reached 100% in all lots. The results are shown in Table No. 8, and in Fig. 5.

Tests No. 6 - February 5, 1920.

Purpose - To determine period of time necessary to produce complete mortality of Dendroctonus brevicomis larvae removed from the outer bark and exposed to constant air temperatures of 100 degrees F.

Basis: 400 larvae divided into 16 lots of 25 larvae each.

Beginning at 8:45 AM the temperature was raised from 44 degrees F. to 100 degrees F. at 9:30 AM, then maintained near this point until 5: PM. Individual lots were removed at 30 minute intervals from the time 100 degrees F. was first reached until

TABLE No.8

Date	Hour	Temperature Fahr: air room	air container	Lot No. removed	Condition of larvae after exposure: living	dead	Mortality: percent	Notes on larvae when first removed from exposure
1920								
Feb	9:00am	75	65					
9								
	9:15	82	80					
	9:30	81	95	a	25	-	0	maximum activity
	9:45	80	100	b	23	2	8. %	activity ceases
	10:00	80	105	c	19	6	24. %	nearly all dormant
	10:15	76	104					
	10:30	76	105	d	-	25	100. %	all dormant
	10:45	74	105					
	11:00	78	105	e	-	25	100. %	" "
	11:15	76	104					
	11:30	76	105	f	-	25	100. %	" "
	11:45	78	105					
	12:00m	78	105	g	-	25	100. %	discoloring
	12:15pm	78	105					
	12:30	76	105	h	-	25	100. %	discolored

Labratory Test No.5. Period of time necessary to produce complete mortality of D.brevicomis larvae which have been removed from the bark and exposed to a constant air temperature of 105 degrees.

close of experiment.

Results are shown by Table No. 9. A low mortality had occurred by the time that 100 degrees F. was reached. Mortality increased steadily and ~~consistently~~ until at the end of 7 hours it reached 100%.

Test No. 7 - February 14 - 15, 1920.

Purpose - To determine period of time necessary to produce complete mortality of Dendroctonus brevicomis larvae removed from bark and exposed to a constant air temperature of 95 degrees F.

Basis: 450 larvae divided into 18 lots of 25 larvae each.

The experiment was started at 4: PM on February 14th and continued until 10:45 AM February 15th. Temperature records were taken at 15 minute intervals. Single lote were removed at 60 minute intervals, beginning at 5:45 PM on the 14th when the temperature first reached 96%.

The results are shown in Table No. 10. The first mortality, (8%), was recorded after 8 hours exposure and increased variably until after 17 hours exposure it reached 96%.

TABLE No.9

Date	Hour	Temperature Fahr. air room	Temperature Fahr. air container	Lot. No. removed	Condition of larvae after exposure: living	Condition of larvae after exposure: dead	Mortality: percent	Notes on larvae when first removed from exposure
1920 Feb. 5	8:45am	80	44					
	9:00	82	80					
	9:15	84	95					
	9:30	84	100	a	24	1	4. %	slight activity
	10:00	82	100	b	23	2	8. %	" "
	10:30	82	98	c	23	2	8. %	" "
	11:00	82	100	d	16	9	36. %	partly dormant
	11:30	78	100	e	18	7	28. %	" "
	12:00m	80	98	f	18	7	28. %	" "
	12:30pm	80	100	g	15	10	40. %	" "
	1:00	80	96	h	13	19	59.4 %	all dormant
	1:30	82	100	i	6	19	76. %	" "
	2:00	82	100	j	12	13	52. %	partly " dormant
	2:30	84	100	k	11	14	56. %	" "
	3:00	82	100	l	1	24	96. %	all dormant
	3:30	84	100	m	1	24	96. %	discoloring
	4:00	84	100	n	1	24	96. %	"
	4:30	84	100	o	-	25	100. %	"
	5:00	82	100	p	-	25	100. %	

Labratory Test No.6. Period of time necessary to produce complete mortality of D.brevicomis larvae removed from the outer bark and exposed to a constant air temperature of 100 degrees.

TABLE No.10

Date	Hour	Temperature Fahr. air: room	Temperature Fahr. air: container	Lot No. removed	Condition of larvae after exposure: living	Condition of larvae after exposure: dead	Mortality percent	Notes on larvae when first removed from exposure
1920 Feb. 14	4:00pm	70	70					
	5:00	75	89					
	5:45	78	96	a	25	-	0	maximum activity
	6:45	77	95	b	25	-	0	" "
	7:45	80	95	c	25	-	0	" "
	8:45	79	93	d	25	-	0	" "
	9:45	78	95	e	23	2	8. %	activity decreasing
	10:45	78	95	f	20	5	20. %	a few dormant
	11:45	80	96	g	17	8	32. %	" " "
Feb. 15	12:45am	78	95	h	20	5	20. %	" " "
	1:45	78	95	i	11	14	56. %	dormancy increasing
	2:45	79	95	j	16	9	36. %	" "
	3:45	76	92	k	15	10	40. %	" "
	4:45	78	94	l	6	19	76. %	nearly all dormant
	5:45	77	95	m	11	14	56. %	" " "
	6:45	77	95	n	10	15	60. %	" " "
	7:45	78	94	o	3	22	88. %	" " "
	8:45	80	95	p	6	19	76. %	" " "
	9:45	77	95	q	2	23	92. %	" " "
	10:45	77	95	r	1	24	96. %	" " "

Labratory Test No.7. Period of time necessary to produce complete mortality of D.brevicomis larvae removed from the outer bark and exposed to a constant air temperature of 95 degrees .

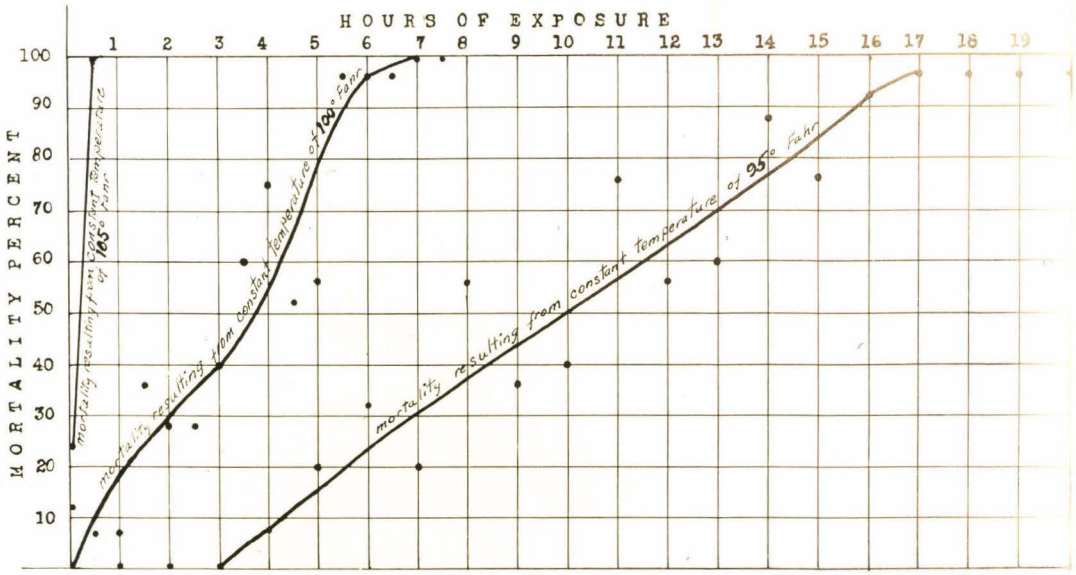

HOURS OF EXPOSURE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
MORTALITY PERCENT
100 90 80 70 60 50 40 30 20 10
mortality resulting from constant temperature of 105° Fahr.
mortality resulting from constant temperature of 100° Fahr.
mortality resulting from constant temperature of 95° Fahr.

CHART SHOWING PERIOD NECESSARY TO PRODUCE COMPLETE MORTALITY OF DENDROCTONUS BREVICOMIS LARVAE UNDER EXPOSURE TO CONSTANT TEMPERATURES AT 95, 100 AND 105 DEGREES FAHR.

In the 3 checks represented by chart, the temperature was raised slowly and then maintained constantly at the desired point for each check. One check was carried to test the result of 110 degrees but complete mortality resulted before that point was reached.

FIG. No. 5 - Chart showing period of exposure necessary to produce complete mortality of Dendroctonus brevicomis larvae removed from the outer bark and exposed to constant air temperatures of 95, 100 and 105 degrees F.

A comparison of tests Nos. 5, 6 and 7, are shown in Fig 5. One other test was attempted to determine the period required to produce complete mortality at 110 degrees F., but as occurred in test No. 4, all larvae were killed by the time that this point was reached.

Within the limitations of the apparatus used, which did not accurately record the degree of atmospheric humidity,* these results indicate that the range of temperatures by which the larvae are most immediately affected may be still further limited to points occurring between 100 and 110 degrees F. 105 degrees appears to be a highly critical point as mortality occurs rapidly when this degree of heat is reached. Any temperature above 110 degrees F. is apparently fatal to all exposed larvae.

Footnote.

* Atmospheric humidity within the jar which contained the larvae was identical to that of the air within the room at the beginning of each test. This humidity decreased as temperatures were raised, but because of ventilation in the cover and opening of jar to

remove larvae, it is not believed that this humidity varied greatly from that of the room under corresponding temperatures. When the air within the jar had reached a temperature of 100 degrees F., a test indicated a relative humidity of 40%. However the sustained low humidity resulting from the long exposures at 95 and 100 degrees F. undoubtedly had an influence on the resultant mortality of the larvae.

4 - Determination of Mortality.

In analyzing bark from laboratory tests considerable attention was given to the method of determining the condition of individual larvae as dead or living. In the bark sections from field tests there was no difficulty on this point as dead individuals after their long exposure were dried and discolored beyond any possible doubt as to their lack of vitality. In the laboratory tests a much shorter period intervened between the removal of bark sections from exposure and their subsequent examination. Where larvae has been exposed to temperatures exceeding 110 degrees F., individuals were usually discoloerd and withered, but those exposed to lower temperatures seldom gave such positive evidence of devitilization. When they

were in this dormant condition the indication mainly relied upon to determine as individuals living or dead was the presence or absence of normal activity and reactions.

Healthy larvae of Dendroctonus brevicomis when removed from the bark under ordinary room temperatures will show considerable activity by movements of the head and anal extremeties, usually lying on the side and contracting the ventral surface of the body. Movements of this sort will always occur as a reaction to external stimuli, such as produced by irritation with a camels hair brush. In larvae which have been affected or killed by abnormal temperatures these movements are entirely lacking.

A difference can also be detected, in color, living larvae being distinguished by a healthy glow to the epidermis, while the color of the affected larvae is usually dull. It was also noted that as the effects of the temperatures increased in degree, a softening of the tissues became apparent, this stage being followed by a yellowish or brownish color, which in turn was

followed by drying and shriveling of the body.

Where only doubtful determination of the vitality could be made individuals were kept for several days and examined at intervals until recovery to normal condtiion occurred or positive evidence was secured as to devitalization.

5 - Mortality of Predatory Larvae.

From Tables Nos. 1, 2 and 3, some records are available indicating the mortality of predatory larvae when subjected to the same range of temperatures and conditions as the Dendroctonus brevicomis broods. So far as has been determined these predatory larvae represent the immature stages of Clerus spp. and Trogositid spp. They are relatively scarce, being represented in the material studied by about 1 individual larvae to the square foot of bark. Records are not conclusive because of this scarcity of materila but they indicate that these predators do not react correspondingly to the same temperatures as the broods upon which they feed.

In Table No. 1, where the bark was not exposed to the sun the mortality of 9 predatory larvae averaged 22% while that of Dendroctonus brevicomis averaged 4.8%.

In Table No. 2, where the bark was exposed with the outside surface toward the sun, the mortality of 17 predatory larvae averaged 25.2% while that of Dendroctonus brevicomis averaged 80.96%.

In Table No. 3, where the bark was exposed with the inside surface to the sun the mortality of 22 predatory larvae averaged 68.2% while that of Dendroctonus brevicomis averaged 94.6%.

In laboratory test No. 3, (Table No. 6) enough predatory larvae were found to indicate the critical temperatures by which they are affected, as shown by the following records from this test:

			Predatory larvae.	
Hour.	Section No.	Bark temper.	Alive.	Dead.
12:00M	5	90	4	0
1:00PM	7	100	1	0
1:30PM	8	106	3	0
2:30PM	10	114	2	2
3:00PM	11	118	0	4
4:00PM	13	128	0	3
4;30PM	14	130	0	2

These results show that no mortality had occurred up to 106 degrees F.; not all of the larvae had been killed at 114 degrees F. but after 118 degrees had been reached no live predators were found.

In test No. 4, two living larvae of Clerus sp. were kept within the jar. It was found that they became dormant when a temperature of 115 degrees F. had been reached.

The possibilities of further investigative work on this phase are evident. Obviously if the broods of Dendroctonus brevicomis can be destroyed by proper exposure of the bark in the sun while a considerable number of their predatory enemies can be preserved, the method offers a decided advantage over that of burning the infested bark which destroys both the bark-beetles and their enemies.

6 - Summary of Observations on Effect of Temperatures.

So far as these investigations have brought to light the fact the broods of Dendroctonus brevicomis are effectively

killed when the infested bark is removed from the tree and properly exposed ~~in~~ to the sun.

Laboratory tests have shown that the overwintering larvae of Dendroctonus brevicomis, either in the outer bark, or removed and exposed to the air are affected by a range of critical temperatures during which mortality occurs and above which no larvae can survive. Allowing for the influence of the ordinary range of atmospheric humidity, the reactions of the larvae to temperatures under laboratory conditions, ranging from 70 to 120 degrees F. have been determined as follows:

70 to 80 degrees F.	Larvae normally active.
81 to 85 degrees F.	Larvae normally active.
86 to 90 degrees F.	Activity increases.
91 to 95 degrees F.	Maximum activity, (Exposed larvae maintain rapid and continuous movement).
96 to 100 degrees F.	Slight activity, (Exposed larvae become dormant after brief exposure, and low mortality may occur).

100 to 105 degrees F. Activity ceases, (Larvae become dormant after brief exposures. Complete mortality of exposed larvae occurs within 30 minutes exposure to 105 degrees F.)

106 to 110 degrees F. Fatal after short exposure. Few larvae survive after temperature reaches 110 degrees. Exposed larvae do not survive 110 degrees F.

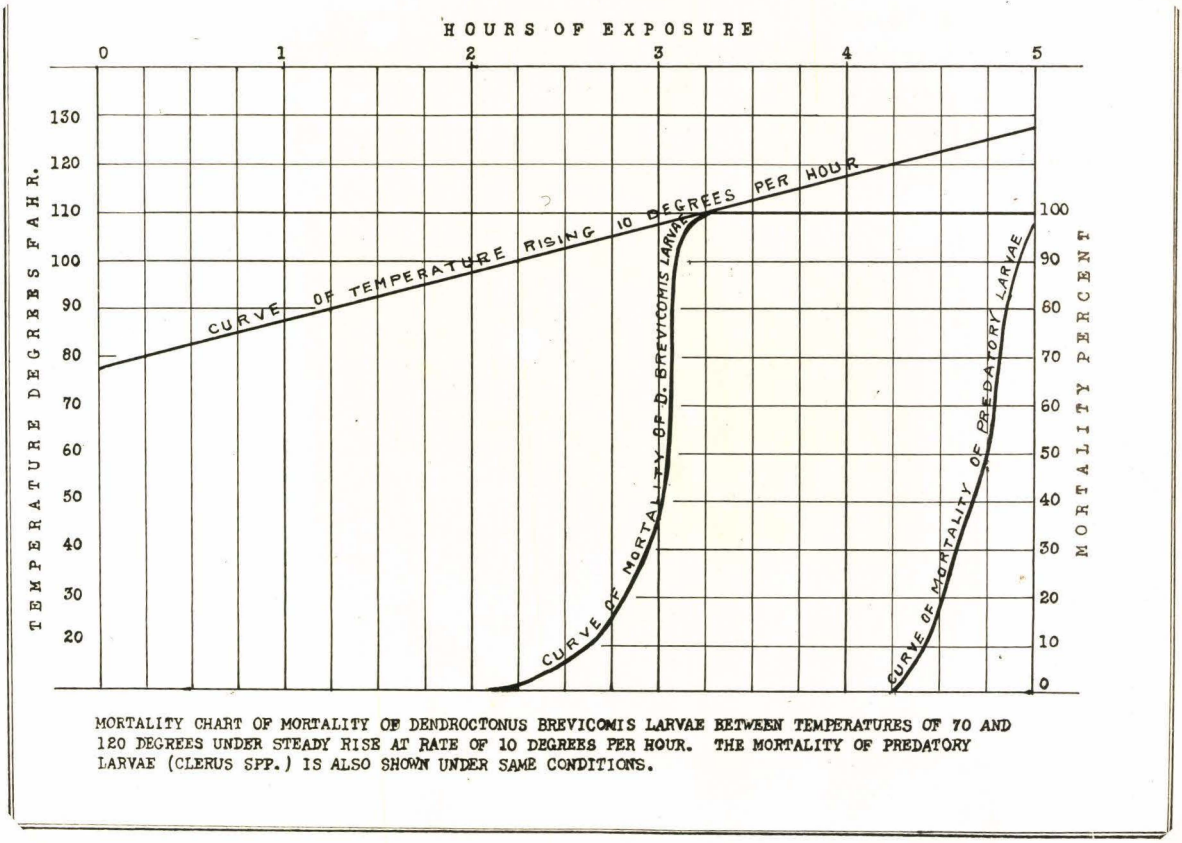
111 to 115 degrees F. Fatal temperatures, (Larvae become discolored after brief exposure).

115 to 120 degrees F. Fatal temperatures, (Larvae become discolored after brief exposure).

The curve indicated by these summarized observations is shown in Fig. No. 6.

III. - FIELD TESTS INDICATING TEMPERATURES OF INFESTED BARK RESULTING UNDER VARYING CONDITIONS OF EXPOSURE.

The ultimate application of this data to practical control of ~~dendroctonus brevicomis~~ the western pine beetle depends upon the temperatures which may occur in infested bark under different conditions of exposure



MORTALITY CHART OF MORTALITY OF DENDROCTONUS BREVICOMIS LARVAE BETWEEN TEMPERATURES OF 70 AND 120 DEGREES UNDER STEADY RISE AT RATE OF 10 DEGREES PER HOUR. THE MORTALITY OF PREDATORY LARVAE (CLERUS SPP.) IS ALSO SHOWN UNDER SAME CONDITIONS.

FIG. No. 6 - Chart summarizing observations on relation of temperatures to mortality of Dendroctonus brevicomis larvae, and predators.

in the field. It does not seem probable that fatal temperatures are reached in infested bark which, in its normal position on the bole of the tree, may be exposed to the sun at periods during the day. The mortality of the broods found in infested bark removed from the tree and exposed on the ground, therefore must be due to fatal temperatures which result because of this position.

1. - Comparative temperatures of infested bark on north and south sides of the same tree, and upon the ground.

Fortunately during the month of February, 1920, a period of clear weather made it possible to arrive at a comparison between temperatures which occur in bark on the north and south sides of an infested tree and in bark sections removed from the tree and placed on the ground exposed directly to the sun.

An infested yellow pine, 20 inches D.B.H. standing on a southern exposure, was selected as a basis for records. The position of the tree was such that after the lower part of the trunk had been cleared of limbs, the south side of the trunk and

ground at base, received direct sunlight from 11:AM to 2:PM. Preceeding and following this period the direct sunlight was broken by occasional shadows of surrounding trees. The basis for the records were the following:

a - A thermometer hung on the shaded side of the tree near the base to record air temperatures.

b - A thermometer imbedded in the bark on the north side of the tree shaded from the sun throughout the day.

c - A thermometer imbedded in the bark on the south side of the tree where it received maximum sun exposure.

d - A thermometer imbedded in a section of bark removed from the tree and placed on the ground at its base where it received maximum sun exposure.

The first day, February 10th, was largely given over to setting the thermometers and preparing the experiment. The following maximum temperatures were recorded, however, at 1:45PM.

Air temperature in shade ..... 60 degrees F.

Temperature in bark on north side of tree ..... 54 degrees F.

Temperature in bark on south side of tree ..... 70 degrees F.

Temperature in bark removed from tree and placed on the ground .... 93 degrees F.

On the following day, February 11th, temperature records were taken at 15 minute intervals from 10:AM to 3:PM.

Time	(a) Air Temp.	(b) Bark on north side of tree.	(c) Bark on south side of tree.	(d) Bark placed on ground in sun.
10:00AM	50	43	50	58
10:15AM	54	44	52	67
10:30AM	51	44	56	70
10:45AM	50	44	52	66
11:00AM	60	45	56	70
11:15AM	63	48	60	82
11:30AM	61	49	64	91
11:45AM	65	49	64	94
12:00 M	64	53	65	98
12:15PM	63	55	67	99
12:30PM	64	56	69	101
12:45PM	63	56	70	101
1:00PM	62	56	70	102
1:15PM	64	57	72	104
1:30PM	66	58	73	104
1:45PM	64	59	74	103
2:00PM	62	58	74	100
2:15PM	55	57	70	80
2:30PM	53	54	66	74
2:45PM	52	53	63	68
3:00PM	50	52	60	62
3:15PM	48	51	58	56

The curve of these temperatures is shown in Fig. 7 .

The fact that the bark on the south side of the tree did not rise more than 8 degrees F. above the normal air temperature is probably due both to its vertical position and its contact with the sapwood. At the maximum the suns rays at this season of the year strike at about 50 degrees from the vertical, thereby limiting the amount of heat absorbed by bark on the bole of the tree, while the bark placed on the ground was tipped so as to expose it at a direct angle of nearly 90 degrees. It is also probable that a considerable amount of the heat collected by bark on the tree was absorbed by the moist sapwood with which it was in contact.

2 - Comparative temperatures of infested bark sections removed from tree, placed in shade and exposed to direct sunlight.

Further tests were carried out under field conditions by placing one bark section in the sun, a corresponding section in

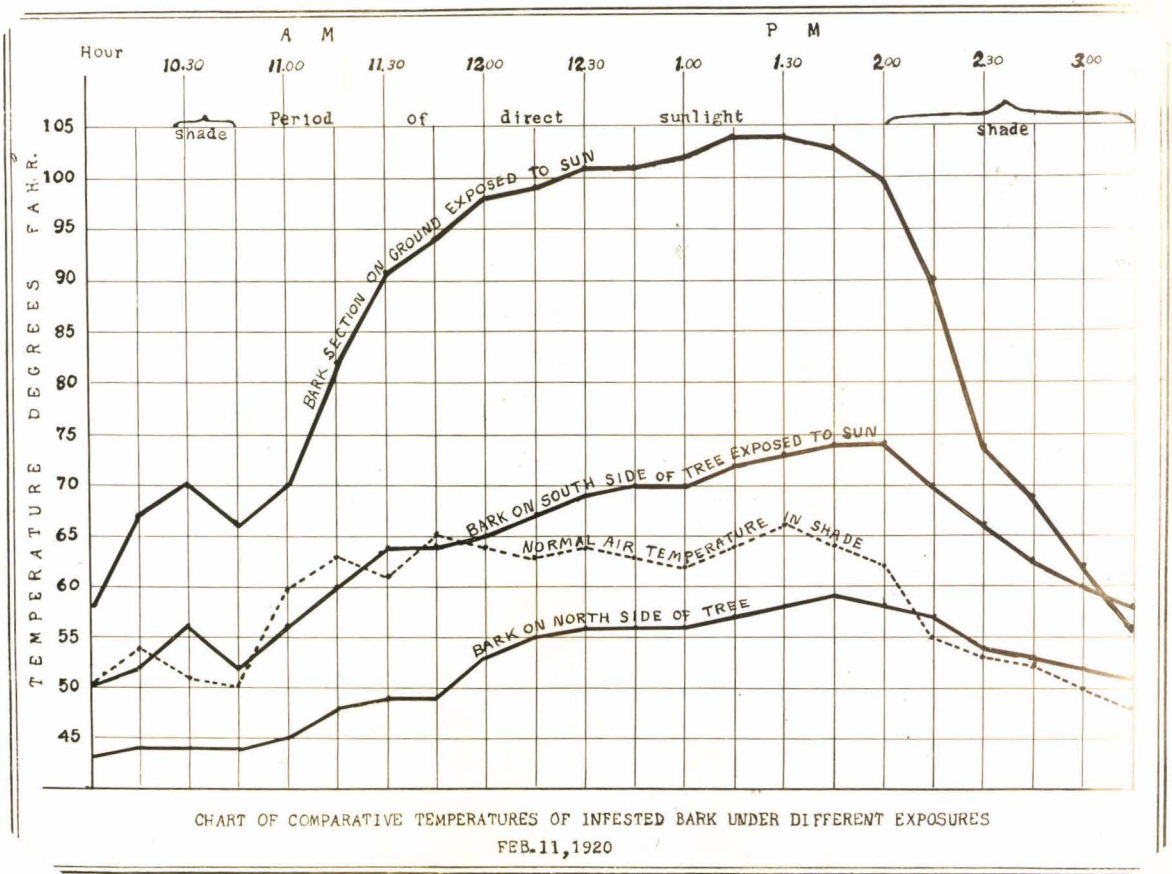


CHART OF COMPARATIVE TEMPERATURES OF INFESTED BARK UNDER DIFFERENT EXPOSURES
FEB. 11, 1920

FIG. NO. 7 -

the shade and recording progressive temperatures in each together with air temperatures in the shade. The following temperatures were obtained on Frebruary 12th.

Time.	Air temp. in shade.	Bark kept in shade.	Bark kept in sun.
10:00AM	36	35	36
10:30AM	40	35	68
11:00AM	44	38	80
11:30AM	44	39	88
12:00 M	49	43	92
12:30PM	52	48	96
1:00PM	54	50	99
1:30PM	55	52	100
2:00PM	58	55	100
2:30PM	59	58	100
3:00PM	59	58	98
3:30PM	59	58	96
4:00PM	61	59	78
4:30PM	56	58	61

These records were continued on four succeeding days with during which the following maximums were recorded:

Date.	Time.	Maximum air temperature.	Maximum bark temperature in the sun.
Feb 13th.	2:30PM	59	110 *
Feb 14th.	2:30PM	63	105
Feb 16th.	2:30PM	60	106 **
Feb 17th.	2:30PM	60	96

Footnote.

* A section of thin bark analyzed after 4 days exposure found brood had suffered 94% mortality.

** Fairly thick bark. Section analyzed after 3 days exposure contained a mortality of 46%.

That the maximum temperatures resulted in a mortality of the broods in the larval stage in some of the bark sections exposed in these tests has shown by subsequent analysis. It was noted, however, that this mortality varied greatly in degree due to factors which may be determined by continuation of the field experiments.

It is considered, however, that the method suggested

offers considerable promise of success if applied to the control of the western pine beetle during the late spring and summer, when higher temperatures result which are probably capable of effectively killing the broods in all stages.

SUMMARIZING STATEMENT.

Field experiments carried on by the Bureau of Entomology in the Sequoia National Park, Calif. during the season of 1919 indicate that broods of the western pine beetle do not emerge seccessfully from infested bark which has been removed from the tree and placed in positions where it is exposed directly to the sun during the heat of the day. In the analysis of bark sections which had been thus exposed, it was found that all stages of broods in the inner and outer bark, from small larvae to new adults had been killed. Where the bark had been placed on the ground with inside surface to the sun, the mortality averaged 94.6%; where the outer surface was exposed under similar conditions mortality averaged 80.9%. Where the bark had been left on the log or removed and placed in shaded positions

mortality averaged 4.8%.

Subsequent experiments carried out under laboratory control at Ashland, Oregon, indicate that the larvae of the western pine beetle undisturbed in the outer bark are affected by a range of critical high temperatures below which no mortality is evident and above which no larvae survive. These critical temperatures were found to be between 95 and 115 degrees Fahr. Sustained exposure ~~of the bark reached~~ to bark temperatures ranging from 95 to 100 degrees F. produced low but appreciable mortality; the degree of this mortality increased at temperatures between 100 and 110 degrees F; brief exposures at 110 degrees F. resulted in high mortality; while no larvae were found which survived bark temperatures of 115 degrees F.

When the larvae were removed from the outer bark and exposed to air temperatures increasing at the rate of 10 degrees F. per hour it was found that normal or maximum activity was maintained until a temperature of 96 degrees F. was reached. Beyond this point activity decreased, dormancy occurred at 100

degrees F., and mortality increased rapidly as the temperature rose above this latter point. No exposed larvae survived an air temperature of 110 degrees F. It was also found that exposure of the exposed larvae to a steadily maintained air temperature of 95 degrees F. produced a mortality of 96% in 17 hours. Similar exposure to a temperature of 100 degrees F. ~~will~~ produced 100% mortality in 7 hours, while an exposure to a temperature of 105 degrees F. produced 100% mortality in 30 minutes.

In further tests carried on in the field at Ashland, Oregon, during the month of February, it was found that under a maximum air temperature of 66 degrees F., the bark on the north or shaded side of an infested tree reached a maximum of only 58 degrees F., bark in the sun on the south side of the tree reached a maximum of 74 degrees F., while bark removed from the tree and placed on the ground with inside surface exposed to the sun from 10:AM to 2:PM reached a maximum of 104 degrees F.

It is evident that the killing of broods of the western pine beetle which has been recorded in bark removed from the tree and exposed to the sunlight during the summer season is largely due to temperatures produced by this exposure that are equal to or exceed the critical maximums of 100 to 115 degrees F.

Control of the western pine beetle during the summer season offers some very evident advantages but has been considered impracticable because of the fire risk involved in burning the infested bark to destroy the broods. It is believed that the method of killing broods by proper exposure of the infested bark to sunlight offers such possibilities for success that it deserves a thorough test in control operations. Further detailed investigations are planned to adequately determine the proper application of this method.

PLATE I.

Mortality of Broods of the Western Pine Beetle in Infested Bark Exposed to Direct Sunlight.

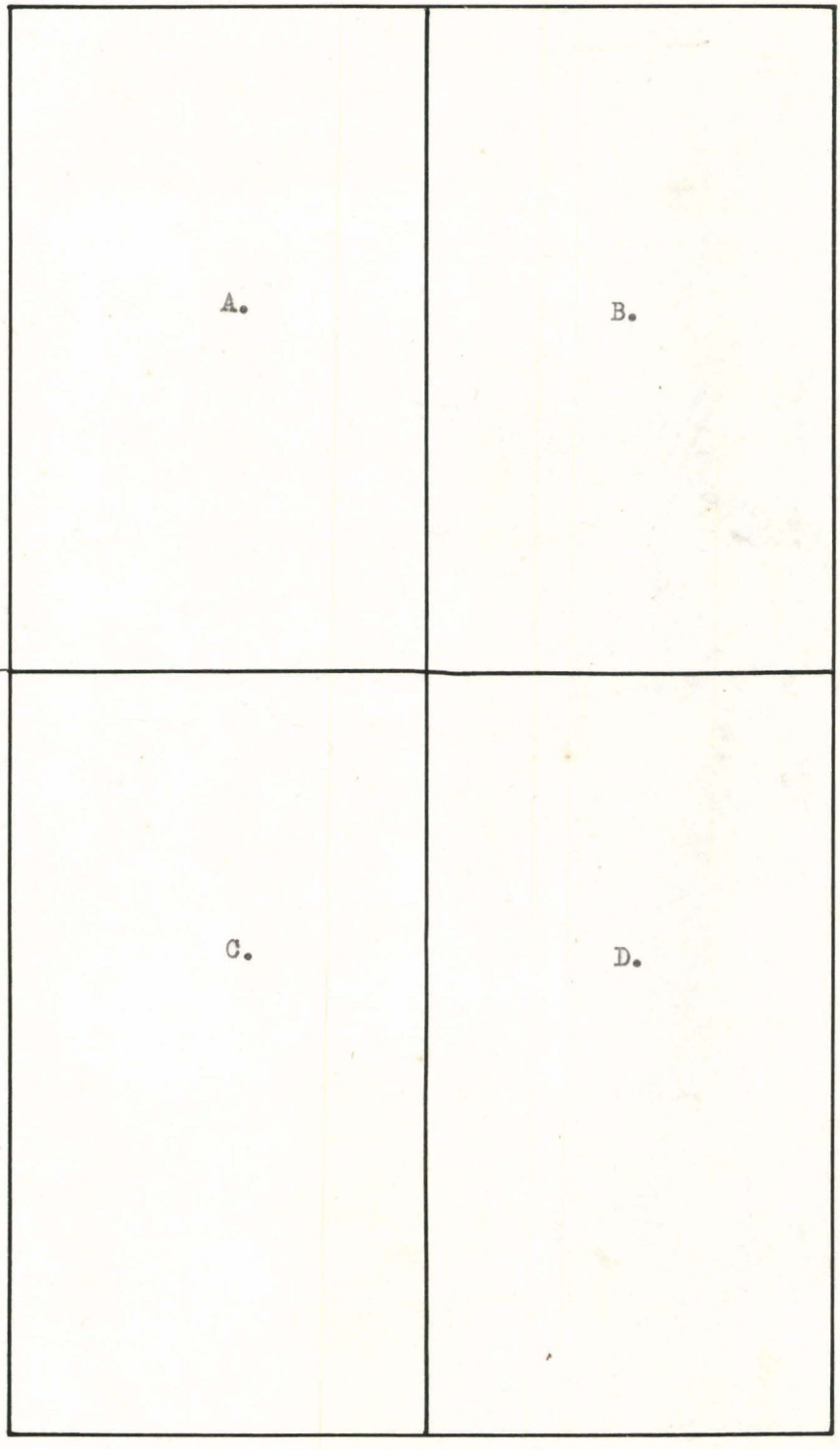


PLATE 2. Mortality of Broods of the Western Pine Beetle in Infested Bark Exposed to Direct Sunlight.

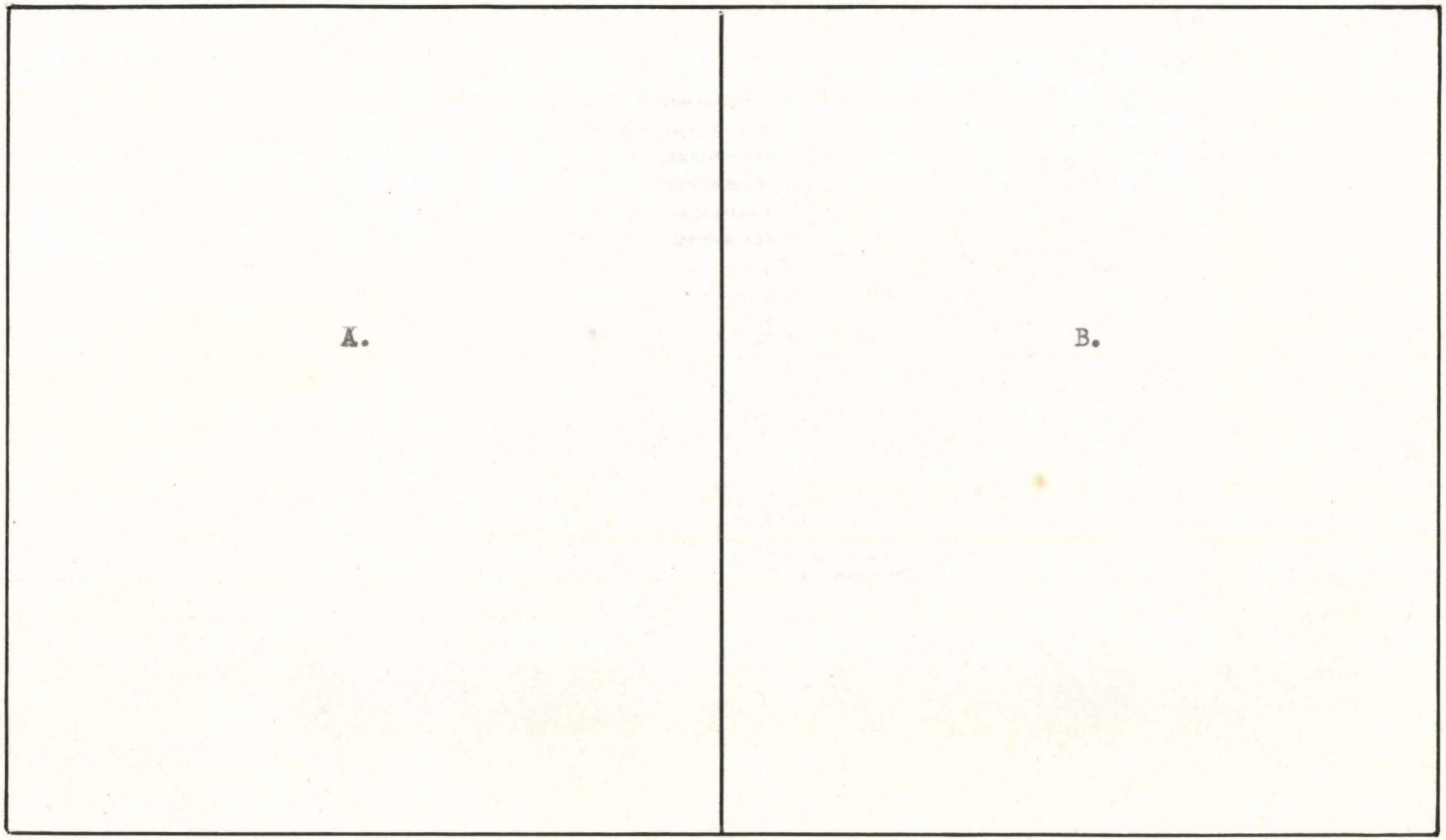


Plate I
a

a-1:

a-2:

PLATE I. A . Sections of infested bark with outer surface removed, showing,

a-1: living larvae of D. brevicomis in galleries in outer bark.(Section removed from tree and kept in shaded position)

a-2: dead larvae of D. brevicomis in galleries in outer bark.(Section removed from tree and kept in positions exposed to sun during July and August,)

Plate 1
B

PLATE I B

Bark sections showing dead larvae, pupae and new adults of D.brevicomis in infested bark exposed to the sun during August. Section on left shows relative position in outer bark where dead broods were found.

Plate I
C

PLATE I C

Inner surface of infested bark removed from the tree and exposed to direct sunlight during July and August. No exit holes were found either on the inner surface which was exposed to the sun, or the outer surface which was placed next to the ground.

(Enlarge to 2¾×4 in)

PLATE I D

Inner surface of infested bark removed from same as C tree and kept in shaded position during July and August . Successful emergence of brood is indicated by numerous exit holes on inner surface. No exit holes occurred on outer surface which was placed next to the ground.

(Enlarge to 2¼×4 in)

Plate II
a

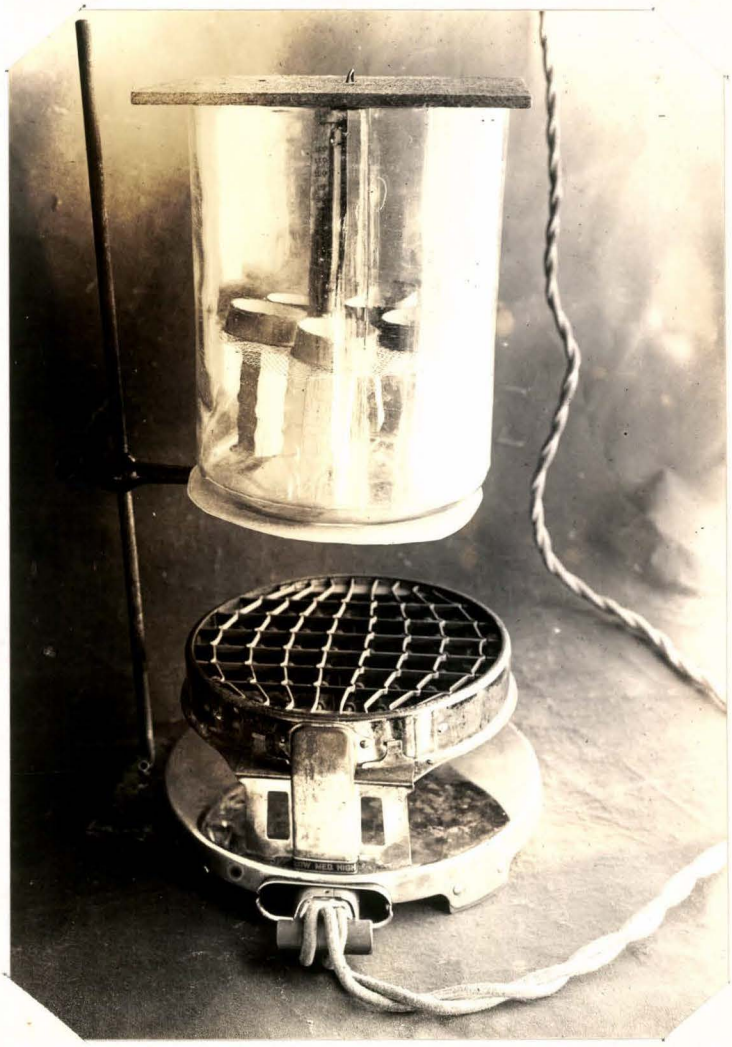


PLATE II - A: - Apparatus used in controlling air temperatures to which Dendroctonus brevicomis larvae, were exposed after removal from the outer bark. The glass jar was used as a general container. Individual lots of larvae were placed in small pasteboard boxes resting upon a screen within the jar. Temperature was regulated by controlling switch of electric disc, and by raising or lowering container above the disc.

Plate II
B

PLATE II - B: - Type of thermometer used in testing temperatures of infested bark. b-1, type of stirring rod thermometer used. b-2, thermometer imbedded in bark which was used as a basis for records. b-3, larvae in natural position in outer bark.